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Chapter 2

Accounting for the Impact of Local and Spill-in Public Research, Extension, and Roads on U.S. Regional Agricultural Productivity, 1980-2004¹

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2.1 Introduction

The study of the contribution of research investment to farm production and agricultural productivity was pioneered by Griliches (1958, 1964), Evenson (1967), and their associates. The benefit of public research in agricultural productivity growth has been documented in numerous studies since their seminal work. Based on literature surveys by Evenson (2001), Alston *et al* (2000), Huffman and Evenson (2006), and Fuglie and Heisey (2007), the rate of return estimates for agricultural research are high. In general, the rates of return to federal-state investment in agricultural research are in the range of 20 to 60% (Fuglie and Heisey, 2007).

The high rate of return to research spending is partly attributed to spillover effects, i.e., the adoption of technologies developed in one region or institution by producers in another region or institution (Evenson 1989, 1998). Griliches (1992), referring to R&D spillovers between firms, addressed the contribution of R&D spillovers in productivity growth indicating that "...where R&D returns can account for up to half of the growth in output-per-man and about three-quarters of the measured TFP growth, most of the explanatory effect coming from the spillover component, which is large, in part, because it is the source of increasing returns...". In the context of public agricultural R&D, studies of the U.S. agricultural sector have investigated R&D spillovers between States, since state universities are agricultural experiment stations have historically been a critical source of local agricultural innovation.² Huffman *et al* (2002), Yee *et al* (2002),

¹ The views expressed herein are those of the authors, and not necessarily those of the U.S. Department of Agriculture.

² The United States public agricultural research system is a Federal-State partnership dating back to the late 19th Century. Through a combination of Federal, State and non-government funds, state institutions account for 60-70% of the research expenditures of this system, with USDA intramural research accounting for the

Alston *et al* (2010), and Plastina and Fulginiti (2011) have reported high social rates of return to state agricultural research, where “social” returns include the economic impact of interstate R&D spillovers, as opposed to “local” returns which consider only the in-state benefits from that research. However, these studies are not able to explain why states in similar regions, benefitting from research spill-ins from neighboring states, may nonetheless experience significantly different rates of productivity growth. Nor are they able to say much about the main channels for dissemination of technology and technical information.

According to the USDA-ERS production accounts, during 1980-2004 average annual agricultural productivity growth rates ranged from a low of 0.95% in Washington State to a high of 3.18% in Massachusetts. Among USDA production regions (see figure 2.1), it ranged from 1.53% in the Appalachian region to 2.60% per annum in the Corn Belt. Among the ten production regions five had average annual growth rates above 2% (the Corn Belt, the Northeast, Northern Plains, Delta, and Lake States). However, the performance of individual states within regions could be heterogeneous or relatively uniform. From Figure 2.2, Appalachian states have widely different productivity growth trends, while Lake States have a more uniform trend. This observation leads us to hypothesize that while there might be important differences in R&D spending across states, there could also exist variations in other public goods that are intimately related and could affect how local R&D affects productivity growth, such as investments in agricultural extension services and road infrastructure.

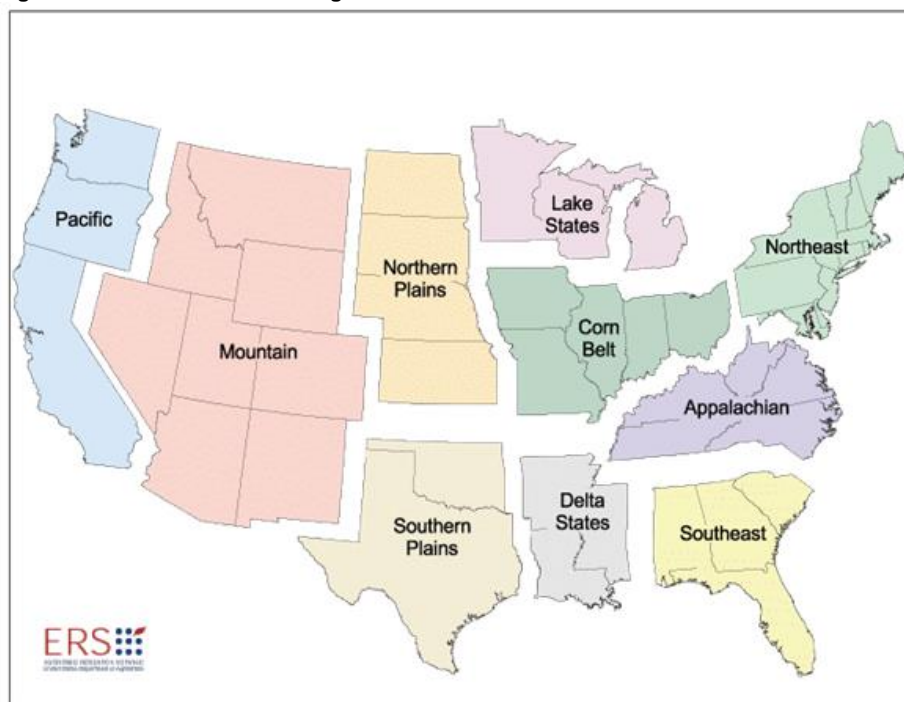
Evenson (2001) reviews a number of studies on the impact of research and extension programs and concludes that extension activities also plays an important role in promoting agricultural productivity growth. Antle (1983) reinforced the importance of public transportation infrastructure in enhancing agricultural productivity growth in an international comparisons study. He asserts that “...the extent to which farmers are able to use new technologies to their advantage depends on the costs and benefits of learning and using them. These costs and benefits are hypothesized to be a function of the country’s stock of infrastructure capital and the resulting costs of infrastructural service.” In a study of U.S. agriculture, Paul *et al* (2001) also found that the transportation network enhanced U.S. agricultural productivity growth.

In this study we examine the role of public R&D expenditures, R&D spill-ins, extension activities, and road infrastructure in U.S. agricultural productivity growth. We hypothesize that a convenient transportation network can provide farmers with an easier way to acquire new technology as it lowers the costs of obtaining inputs that embody new technology, including information. Extension activities may strengthen the dissemination and absorption of technical information. Finally, research spill-ins from other states

rest. State institutions focus primarily on the agricultural concerns of their home state, but the potential for significant inter-state and inter-regional R&D spillovers has important implications for science policy in such decentralized R&D systems

within the same geo-climatic region could amplify the impact of local R&D on productivity growth. In this way, extension activities, road infrastructure, and R&D spill-ins may act as a catalyst in stimulating local technology development and diffusion as well as utilization of new technical information.

Figure 2.1 - USDA Production Regions



Data Source: USDA-ERS (<http://www.ers.usda.gov/data/farmincome/USDA-Production-regions.htm>)

States according to region:

Northeast: NH, PA, ME, MD, RI, MA, DE, CT, VT, NY, NJ

Lake States: MN, MI, WI; Corn Belt: OH, IA, MO, IN, IL

Appalachian: WV, TN, NC, VA, KY

Southeast: SC, AL, GA, FL

Delta: LA, AR, MS

Northern Plains: ND, SD, KS, NE

Southern Plains: TX, OK

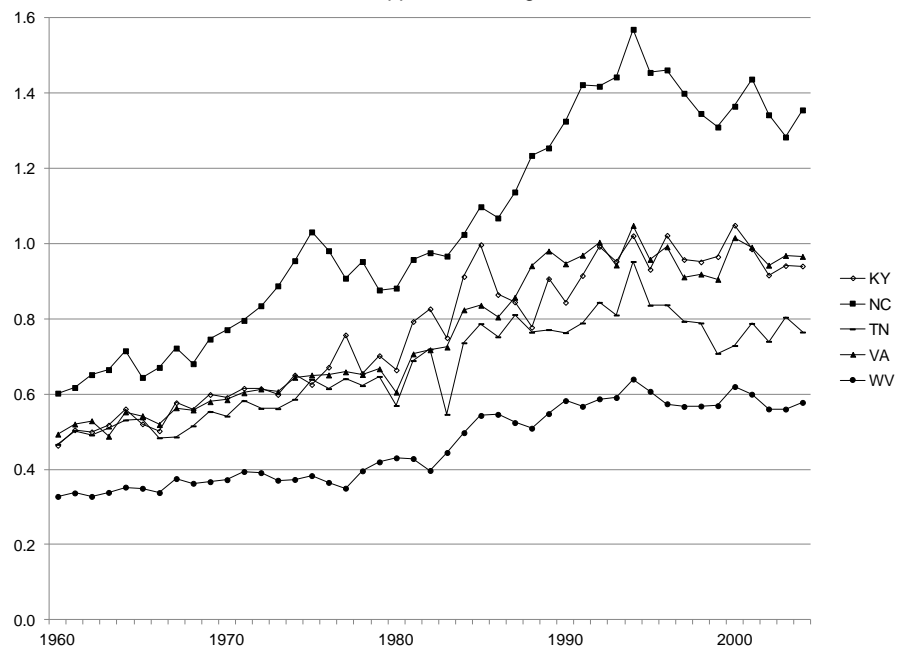
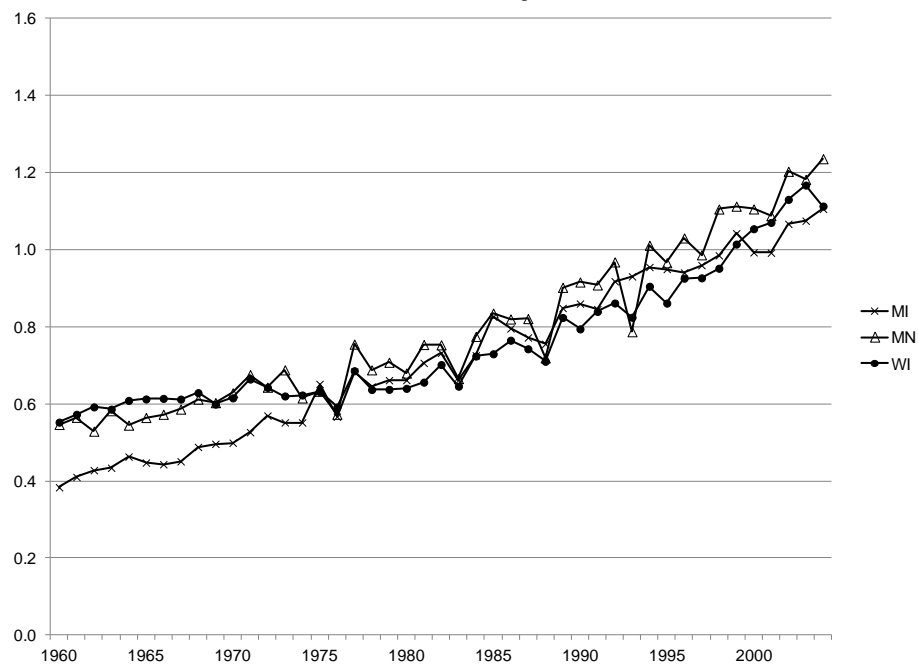
Mountain: CO, UT, AZ, NM, WY, NV, ID, MT;

Pacific: OR, CA, WA.

The objective of this chapter is to investigate how local public goods such as extension activities, R&D spill-ins, and road infrastructure can help explain the heterogeneity in agricultural productivity growth among U.S. states and USDA production regions. To do so, we first estimate the impact of public research investments on U.S. agricultural productivity growth using a dual cost function and state-by-year panel data. Second, we evaluate the differential impacts of extension activities and road infrastructure on R&D's contribution to productivity growth. We examine the interaction between local R&D stock and research spill-ins, extension services, and road infrastructure across regions and states. We compare results from models with and without the extension and infrastructure variables in order to assess the impact of these variables on estimates of the rate of return to investment in research.

Figure 2.2 – Heterogeneity in Agricultural Productivity Growth Among U.S. States

(Total Factor Productivity Index, Alabama in 1996 =1.0)

Panel A. TFP Indexes for States in the Appalachian Region**Panel B. TFP Indexes for States in the Lake States Region**

2.2 Model

We estimate a variable cost function to evaluate the benefit of R&D investments on the cost of production. A reduction in the cost of producing a given level of output can be interpreted as a productivity improvement. To explain costs, we construct variables representing own R&D stocks, spill-ins R&D stock, extension activities (*ET*), and road infrastructure (*RO*), and estimate their impact on variable cost. We allow for interactions among these variables in order to capture their potential enhancing effect on the diffusion of technical information. We fit a translog variable cost function using state-by-year panel data to estimate productivity growth in US agriculture by state. We assume that each state produces three outputs, livestock (*V*), crops (*C*) and other farm related goods and services (*O*) using four variable inputs including land (*A*), labor (*L*), materials (*M*), and capital (*K*), and one fixed input, own agricultural R&D stock (*RD*). We include extension activities (*ET*), road density (*RO*), and R&D spill-in (*SR*) variables, which we refer to as efficiency variables (*E*), to examine their interaction with local R&D. The total variable cost (*TVC*) function is:

$$\begin{aligned} \ln TVC = & \alpha_0 + \sum_{n=1}^{10} \sum_{i=1}^4 \alpha_{ni} D_n \ln w_i + \sum_{l=1}^3 \beta_l \ln y_l + \gamma_{RD} \ln RD + \frac{1}{2} \gamma_{RDRD} \ln RD \ln RD + \frac{1}{2} \sum_{i=1}^4 \sum_{j=1}^4 \alpha_{ij} \ln w_i \ln w_j + \\ & \frac{1}{2} \sum_{l=1}^3 \sum_{k=1}^3 \beta_{lk} \ln y_l \ln y_k + \sum_{i=1}^4 \sum_{l=1}^3 \delta_{il} \ln w_i \ln y_l + \sum_{i=1}^4 \theta_{iRD} \ln w_i \ln RD + \sum_{l=1}^3 \phi_{lRD} \ln y_l \ln RD + \sum_{h=1}^3 \xi_{hRD} \ln E_h \ln RD + \\ & \sum_{h=1}^3 \sum_{i=1}^4 \rho_{ih} \ln E_h \ln w_i + \sum_{i=1}^4 \rho_{iW} \ln W \ln w_i \end{aligned} \quad (2.1)$$

where w_i are input prices, y_l are output quantities, D_n are regional dummy variables³, W is a weather variable, and the α 's, β 's, γ 's, δ 's, θ 's, ξ 's, ρ 's, and ϕ 's are parameters to be estimated.

We impose symmetry and linearity homogeneity in prices in the estimation. Using Shephard's lemma, the cost share for input i is:

$$S_i = \sum_{n=1}^{10} \alpha_{ni} D_n + \sum_{j=1}^4 \alpha_{ij} \ln w_j + \sum_{l=1}^3 \delta_{il} \ln y_l + \theta_{iRD} \ln RD + \sum_{h=1}^3 \rho_{ih} \ln E_h + \rho_{iW} \ln W \quad (2.2)$$

The estimated system of equations includes the total variable cost equation (1) and three input cost share equations (2). The parameters are estimated using Iterative Seemingly Unrelated Regression (ITSUR). To test for the effect of extension activities and roads on productivity growth we fit the system of equations twice, once with these variables

³ To conserve degrees of freedom, we only introduce the region dummies in the first-order terms to allow the cost shares to differ among production regions.

included and once without. Model 2 include all variables of interest, while Model 1 is a special case that sets all parameters on extension and roads to zero.

To account for the impacts of local public goods we calculate the cost elasticity of own R&D and other efficiency variables E_h based on parameter estimates from the above models. A negative elasticity indicates a cost-saving effect. These are:

$$\varepsilon_{RD} \equiv \frac{\partial \ln TVC}{\partial \ln RD} = \gamma_{RD} + \gamma_{RDRD} \ln RD + \sum_{i=1}^4 \theta_{iRD} \ln w_i + \sum_{l=1}^3 \phi_{lRD} \ln y_l + \sum_{h=1}^3 \xi_{E_h RD} \ln E_h \quad (2.3)$$

$$\varepsilon_{E_h} \equiv \frac{\partial \ln TVC}{\partial \ln E_h} = \xi_{E_h RD} \ln RD + \sum_{i=1}^4 \rho_{iE_h} \ln w_i \quad (2.4)$$

The elasticity ε_{RD} measures the percent cost reduction from a 1% increase in local R&D stock. The elasticity ε_{E_h} measures the percent cost reduction from a 1% increase one of the efficiency variables E_h . If the sign of ε_{RD} , or ε_{E_h} is negative, then an increase in own R&D stock or in the efficiency variables E_h reduces total variable cost.

The marginal effect of the efficiency variables on R&D is given by

$$\frac{\partial \varepsilon_{RD}}{\partial \ln E_h} = \xi_{E_h RD} \quad (2.5)$$

If the sign of $\xi_{E_h RD}$ is negative, it implies that an increase in extension services or road density enhances the impact of local R&D by enabling it to reduce costs even further. Based on these estimates and following Wang *et al.* (2009) we calculate internal rates of return to agricultural research investments for Models 1 and 2. The local internal rate of return to research r_l reflects the benefit from R&D investment by a state to its own agricultural sector. It is the discount rate that equates one dollar of investment today with the present value of all future production cost savings resulting from that research. It is found by solving the following equation (see appendix for the derivation):

$$1 = - \left[r_{RD} + r_{RDRD} \ln RD + \sum_{i=1}^4 \theta_{iRD} \ln w_i + \sum_{l=1}^3 \phi_{lRD} \ln y_l + \sum_{h=1}^3 \xi_{E_h RD} \ln E_h \right] * \frac{TVC}{RD} * \sum_{\tau=1}^s \frac{\omega_{\tau}}{(1+r_l)^{\tau}} \quad (2.6)$$

where s is the maximum number of years research investments affect future production and the ω_τ 's are the weights used to construct the R&D knowledge capital stocks from annual R&D expenditures from annual expenditures (see appendix).

Taking into account the benefits of R&D done in one state to other states (R&D spillovers), the social internal rate of return can be derived by solving for r_2 in the following equation (see appendix for the derivation):

$$1 = - \left[r_{RD} + r_{RDRD} \ln RD \sum_{i=1}^4 \theta_{iRD} \ln w_i + \sum_{l=1}^3 \phi_{lRD} \ln y_l + \sum_{h=1}^3 \xi_{E_hRD} \ln E_h \right] * \frac{TVC}{RD} * \sum_{\tau=1}^s \frac{\omega_\tau}{(1+r_2)^\tau} - \sum_{j=1}^{n-1} \sum_{\tau=0}^s (\xi_{SRRD} \ln RD_j + \sum_{i=1}^4 \rho_{iSR} \ln w_{ij}) * \frac{TVC_j}{SR_j} * \frac{\omega_\tau}{(1+r_2)^\tau} \quad (2.7)$$

In this study we calculate local rates of return (r_1) and social rates of return (r_2) based on the parameters and fitted values from two models—one including only the local and spill-in R&D variables (Model 1) and one also incorporating agricultural extension spending and road density (Model 2).

2.3 Data Sources and Description

To estimate the system of equations (1) and (2) we need information on input cost shares, input prices, output quantities, research expenditure, extension activities, and road density. We describe our data and discuss trends in these variables over the study period in this section.

2.3.1 Input Shares, Input Prices, and Output Quantities

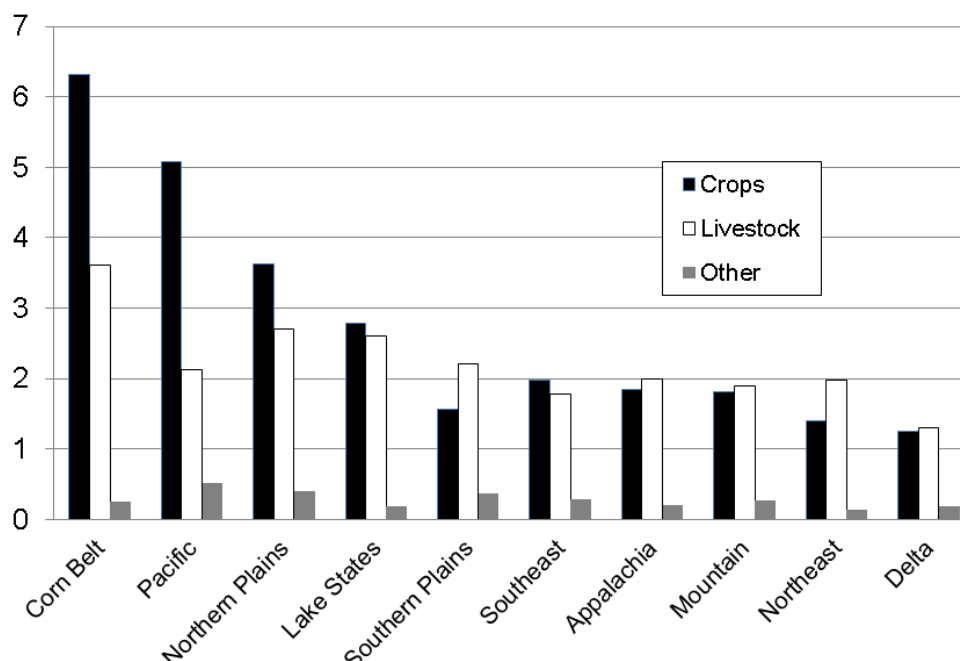
We use annual data for the 48 contiguous states from 1980 to 2004 for our analysis. The agricultural production data were drawn from the state agricultural productivity accounts at the U.S. Department of Agriculture, Economic Research Service. The output data were constructed as the nominal output value deflated by the relative price index between the individual state and the base state. Multilateral price indexes were computed following Caves, Christensen, and Diewert (1982) and using detailed data described in Ball *et al* (1999). Figure 2.3 shows average output by region. Among the ten regions, the Corn Belt region has the highest crops and livestock productions. Pacific, Northern Plains regions rank second and third in crop production while Northern Plains and Lake States rank second and third in livestock production. Northeast and Delta regions are two smallest regions among the ten in aggregate output during the 1980 to 2004 period.

As to the inputs shares, intermediate materials accounts for most of the variable cost with an average cost share of 50% between 1980 and 2004. The labor cost share is 23%, followed by capital and land with 17% and 15%, respectively. However, there is

considerable variation among states in cost shares. The highest material share is almost 80% of the total variable cost, while the smallest land share is 3% of the total variable cost. Among the four input prices, land prices varied the most among observations as it reflects differences in land quality across states.

Figure 2.3 - Agricultural Output for U.S. Regions (Average Over 1980-2004)

Billion constant 1996 U.S. dollars per year



Data sources: Authors' calculations from state agricultural productivity accounts, available at U.S. Department of Agriculture, Economic Research Service.

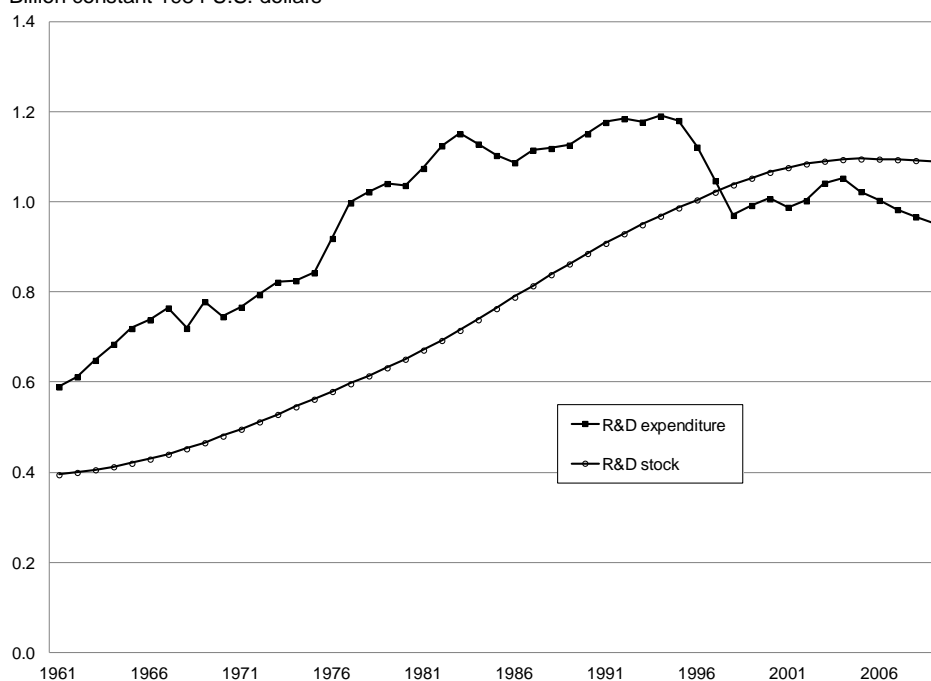
2.3.2 R&D Stocks and R&D Spill-ins

In this study we used a trapezoidal-weight pattern proposed by Huffman and Evenson (2006) to construct R&D stocks from R&D expenditures. The annual agricultural research expenditure data and the research price index used to deflate expenditures are provided by Huffman. Huffman (2009) reported that the public research expenditure data is drawn mainly from the USDA Current Research Information System (CRIS), which contains information on all research projects implemented by USDA's research institutions including the Agricultural Research Service (ARS) and the Economic Research Service (ERS) and the state agricultural experiments stations (SAES) and the veterinary schools/colleges of the land-grant universities. To focus on productivity oriented projects only Huffman (2009) excluded the research expenditures which do not contribute directly to agricultural productivity. Figure 2.4 shows real R&D expenditures

and R&D stocks. Although real R&D expenditures have been flat in recent years, R&D stocks were still increasing as they reflect previous years' research expenditures.

Figure 2.4 Public R&D Expenditures and R&D Stocks in U.S. Agriculture

Billion constant 1984 U.S. dollars



Source: Huffman (2009). Public agricultural R&D expenditures include only spending on productivity-oriented research by land grant universities, state agricultural experiment stations, colleges of veterinary medicine, and relative institutions. See Huffman (2009) for details.

We construct R&D spill-ins stocks based on USDA production regions. We assume that states within the same USDA production region may benefit from each other's research. The R&D spill-ins are measured as follows:

$$SR_i = \sum_{i \neq j} \Omega_{ij} RD_j \quad (2.8)$$

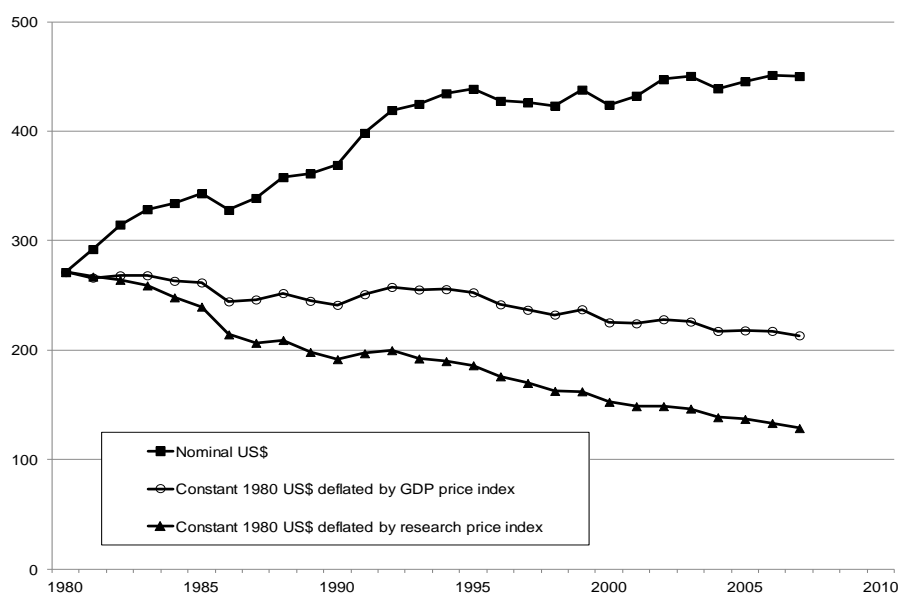
where SR_i is the spill-in R&D stock for state i , Ω_{ij} is the weight used to adjust for the contribution of the j th state's innovations to the i th state, and RD_j is own R&D stock generated by state j . In this study we assume $\Omega_{ij}=1$ for each state other than the own-state within the same production region.

2.3.3 Extension Service, Roads, and Weather

We use total full time equivalent (FTE) extension staff at the state level to construct the extension (ET) capacity indexes for each state. The extension capacity index uses total FTEs as the numerator and the number of farms as the denominator to represent the capacity of the extension service to disseminate technical information. Data on FTEs by state were drawn from the Salary Analysis of the Cooperative Extension Service from the Human Resource Division at USDA. Real extension expenditures, as well as FTE's, have declined over the period of analysis (figure 2.5).

Figure 2.5 Federal Government Expenditures for Agricultural Extension in the United States

Million U.S. dollars



Sources: Extension expenditures from U.S. Department of Agriculture, the Office of Budget and Program Analysis; research price deflator from U.S. Department of Agriculture, Economic Research Service; implicit GDP price deflator from the U.S. Department of Commerce, Bureau of Economic Analysis.'

As to road infrastructure, we construct a road density index to examine its impact on dissemination of local R&D. The road density index was constructed using total road miles excluding local (e.g. city street) miles for each state divided by total land area. We hypothesize that in states with higher road density the cost of disseminating technical information will be reduced and, therefore, the impact of public R&D on productivity will be enhanced. The information was drawn from the Highway Statistics Publication.

Weather is treated as a control variable in this model. We use total precipitation in inches from March to November (Schlenker and Roberts, 2006) to capture the short term shocks caused by the rainfall variation.

2.4 Econometric Results and Returns to R&D, Spillovers, Extension and Roads

Two models were estimated, Model 1 includes only the local and spill-in R&D stock variables while Model 2 also incorporates agricultural extension and road density in the estimation. We fit the total variable cost equation (equation 1) and three input cost share equations (equation (2)) subject to symmetry and linear homogeneity in prices using the Iterative Seemingly Unrelated (ITSUR) approach. Parameter estimates and other statistics from the estimation are given in appendix Table A2.1, excluding the regional dummies. Most coefficients are significant at the 5% level. The curvature condition, checked after estimation, was satisfied locally but not globally. The joint null hypothesis that the extension and road density related parameters are zero was rejected at the 1% level of confidence (see Wald X^2 statistics in table A2.1). The likelihood ratio test, also presented in table A2.1, gives similar results. We conclude that Model 2 is the preferred model.

Using the estimated parameters and equations (3)-(5) we calculate the impacts of changes in own-state R&D and other efficiency variables, including R&D spill-ins, extension services and road density, on productivity growth, as well as the impacts of the efficiency variables on R&D's cost saving effect. When other variables are held constant, 1% reduction in cost caused by the change of variables of interest can be treated as 1% growth in productivity. Table 2.1 shows that the cost elasticities are all negative, indicating that an increase in own state R&D stock, and R&D spill-ins stock in both models reduces costs and, therefore, increases productivity. When the extension and road variables are excluded (model 1) own R&D and spillin R&D have the same mean elasticity, but when these variables are included (model 2) the own R&D elasticity declines and the spillin R&D elasticity increases somewhat. The effect of extension is particular strong. This implies that part of the cost saving effect of own R&D expenditures is generated through its interaction with extension services and road density; excluding these variables from the model appears to bias the impact of R&D on local productivity upward.

Table 2.1 - Cost Elasticities of Local R&D, Extension, Roads, and R&D Spill-ins From Other States

Public good	Elasticity	Model 1: R&D variables only		Model 2: Extension & roads included	
		mean	standard deviation	mean	standard deviation
Local R&D	ξ_{RD}	-0.1578	0.1191	-0.1287	0.0903
R&D spill-ins	ξ_{SRD}	-0.1576	0.0117	-0.1637	0.0103
Extension	ξ_{ET}	---	---	-0.2482	0.0209
Roads	ξ_{RO}	---	---	-0.0361	0.0038

The elasticities measure the percent change in agricultural production cost resulting from a 1% increase in the public good. The negative sign reflects a reduction in production cost.

Across regions, estimates of the R&D elasticities vary considerably and again are usually lower when extension and road variables are included (Table 2.2). Among the ten

Table 2.2 - Cost Elasticity of Local R&D by Region

Region	Model 1: R&D variables only		Model 2: Extension & roads included	
	Mean	SD	Mean	SD
1. Corn Belt	-0.077	0.036	-0.081	0.035
2. Pacific	-0.036	0.095	-0.028	0.064
3. Northern Plains	-0.029	0.039	-0.022	0.042
4. Lake States	-0.078	0.035	-0.080	0.036
5. Southern Plains	-0.045	0.070	-0.045	0.056
6. Southeast	-0.145	0.068	-0.120	0.065
7. Appalachia	-0.183	0.086	-0.154	0.059
8. Mountain	-0.193	0.078	-0.145	0.067
9. Northeast	-0.290	0.107	-0.232	0.068
10. Delta States	-0.138	0.034	-0.107	0.029

SD = standard deviation.

The elasticities measure the percent change in agricultural production cost resulting from a 1% increase in local R&D stock. The negative sign reflects a reduction in production cost.

regions, the investment in public research has a higher productivity impact in the Northeast, Mountain, Appalachian, Southeast, and Delta regions compared to others.

Table 2.3 - Marginal Effects of Efficiency Variables on the Elasticity of Local R&D

Sources	Model 1: R&D variables only		Model 2: Extension & roads included	
	Marginal effect on local R&D	t ratio	Marginal effect on local R&D	t ratio
R&D spill-ins	-0.009	-10.280	-0.009	-12.450
Extension	---	---	-0.015	-18.820
Road density	---	---	-0.002	-4.380

The marginal effect is the effect of a 1% increase in the efficiency variable on the cost elasticity of local R&D stock. The negative value indicates that greater R&D spill-ins, extension activities, and roads increase the rate at which local R&D reduces agricultural production costs.

Based on equations (6) and (7) and using the predicted values from Models 1 and 2, we calculate the local internal rate of return as well as the social rate of return for both models at each observation. We report these estimates by region in table 2.4. The output-share weighted average local internal rate of return, r_I , is 13.0% for Model 1 and 12.5% for Model 2. The weighted average social rate of return is 43.7% for model 1 and 45.1% for model 2. While the difference in the average numbers between models is small we find that the estimates in Model 2 are more varied than the estimates in Model 1. Average differences among regions mask the contributions of Model 2 to our understanding of the heterogeneity across regions and across states. We use coefficient of variation (COV) to show the heterogeneity of the internal rate of return estimates. COV is measured as the standard deviation divided by mean. According to the COV criteria, we can see that Model 2 allows better identification of the differential returns among states within the

same region. Even when states seem to benefit similarly from R&D spill-ins, this model identifies differences in responses to their specific extension activities and road infrastructure.

Table 2.4 – Local and Social Internal Rates of Return (ROR) to Public Agricultural Research by Region (%)

Region	Model 1: R&D variables only						Model 2: Extension & roads included					
	r ₁ : Local ROR			r ₂ : Social ROR			r ₁ : Local ROR			r ₂ : Social ROR		
	Mean	SD	RSE	Mean	SD	RSE	Mean	SD	RSE	Mean	SD	RSE
1. Pacific	12.3	2.3	18.7	34.8	13.3	38.2	9.3	3.2	34.4	37.0	16.5	44.6
2. Southern Plains	20.8	8.1	38.9	52.1	16.6	31.9	20.8	6.6	31.7	54.5	18.4	33.8
3. Corn Belt	11.6	4.2	36.2	53.8	11.2	20.8	13.0	6.0	46.2	55.2	11.5	20.8
4. Lake States	11.0	4.6	41.8	50.1	7.8	15.6	11.3	5.3	46.9	51.1	8.5	16.6
5. Northern Plains	11.9	9.3	78.2	48.7	13.7	28.1	16.2	13.9	85.8	53.0	16.1	30.4
6. Southeast	10.6	2.6	24.5	36.4	10.3	28.3	7.3	5.1	69.9	34.7	9.4	27.1
7. Delta States	10.2	2.4	23.5	35.7	5.7	16.0	7.6	3.3	43.4	34.9	5.9	16.9
8. Appalachia	12.8	5.2	40.6	26.4	10.2	38.6	11.6	5.5	47.4	26.1	9.7	37.2
9. Mountain	11.9	4.6	38.7	39.1	13.9	35.5	9.3	5.2	55.9	40.1	14.3	35.7
10. Northeast	11.9	9.7	81.5	32.3	20.3	62.8	9.9	10.1	102.0	31.1	19.9	64.0
All	11.9	6.6	55.5	39.1	16.6	42.5	10.8	8.0	74.1	39.6	17.6	44.4
weighted average	13.0			43.7			12.5			45.1		

SD indicates standard deviation and RSE indicates relative standard deviation (standard deviation divided by the mean in %).
ROR: rate or return

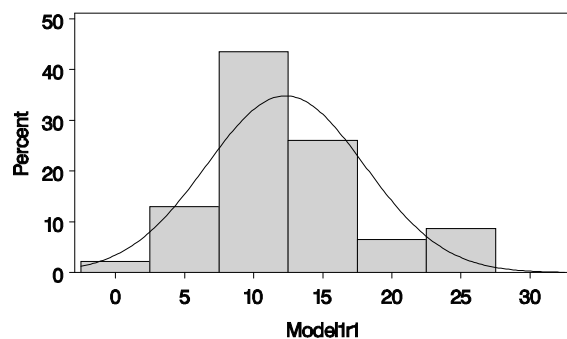
In general, four regions experienced social rates of returns above 50%. They are the Lake States, the Corn Belt, the Northern Plains, and the Southern Plains. These regions are also among the major agricultural production regions in the US. It seems that states within those regions have been benefit more from R&D spillovers than states in other regions. The Appalachian and the Northeast regions have experienced lower social rates of returns. They also play a relatively smaller role in US agricultural production. Figure 2.6 shows the frequency distributions of the local and social internal rate of return among the 48 states for both models. Except for the estimated social rates of return in Model 1, the rates of return estimates are not normally distributed and differ across models. Figure 2.6 also shows that most local rates of return are below 15% and most social rates of return are above 30%. This implies that when addressing the benefits from investment in research a common rate of return applied to every state and every time period may be misleading.

Figure 2.7 and figure 2.8 provide additional information on the distribution of internal rates of return among models and states. The median, mean, interquartile range percentile values, as well as the maximum and minimum value are indicated in the Box-Whiskers plots in figure 2.7 for the local and social rates of return estimated by both models. The median local rate of return, r_1 , is 12% in Model 1 and 10% in Model 2, while the median social rate is much higher, 38% in Model 1 and 37% in Model 2. We also find that the variability is larger in Model 2, as the local rate ranges from 0.2% to 31.4%, while the social rate ranges from 2.3% to 75.0%, a much wider interval than for Model 1. We group the 48 states into ten regions and present the estimates by region in figure 2.8, panels A, B, C, and D. Figure 2.8 shows that the benefits from public research differed from region to region. It also demonstrates a wider interquartile range of rates of return in Model 2 in most regions, especially for the local rates of return. It shows that returns to

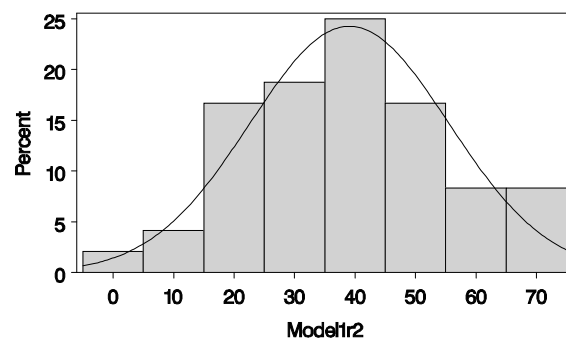
research are not only conditional on each state's natural resource endowments, but also may be affected by its public infrastructure, its extension activities, and its neighbor's research performance.

Figure 2.6 - Distribution of the Rate of Return to Agricultural Research Among U.S. States (%)

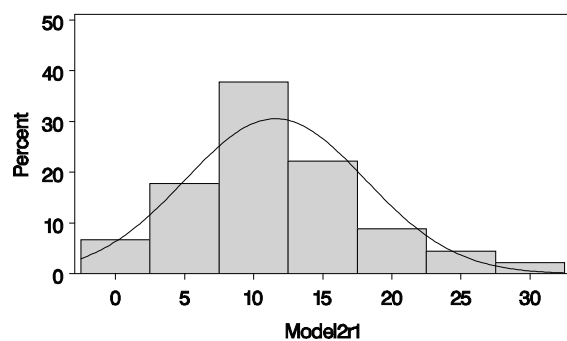
Panel A. Local internal rates of return--Model1 (R&D variables only)



Panel C. Social rate of return—Model 1 (R&D variables only)



Panel B. Local internal rates of return--Model2 (Extension & roads includes)



Panel D. Social rate of return—Model 2 (Extension & roads includes)

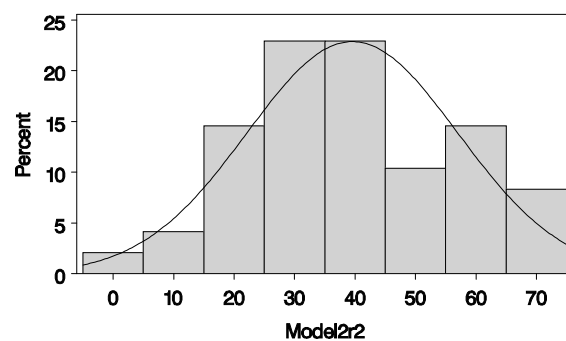


Figure 2.7 - Distribution of Rates of Return to Research by Models (Box and Whiskers plots)

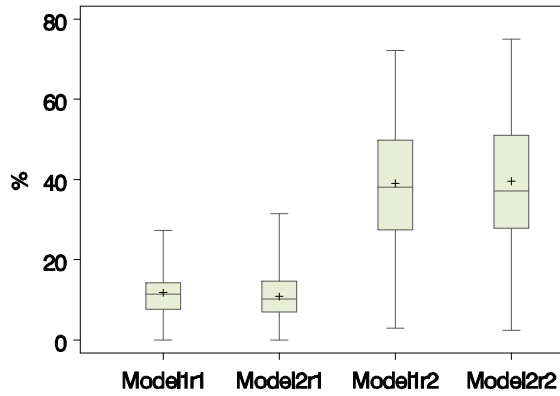
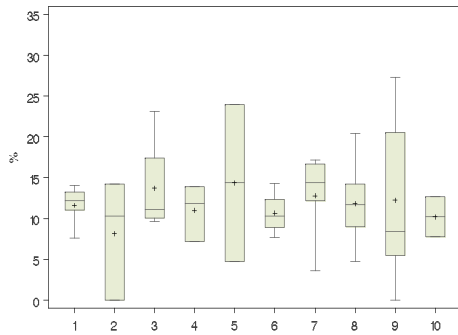
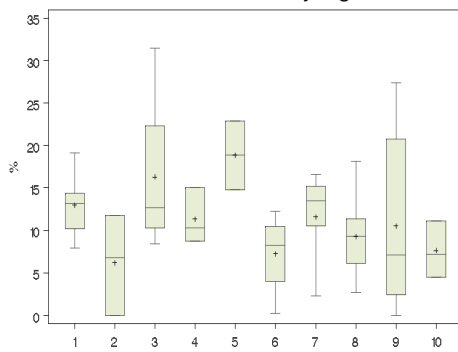


Figure 2.8 - Distribution of Rates of Return to Research among Regions (Box and Whiskers plots)

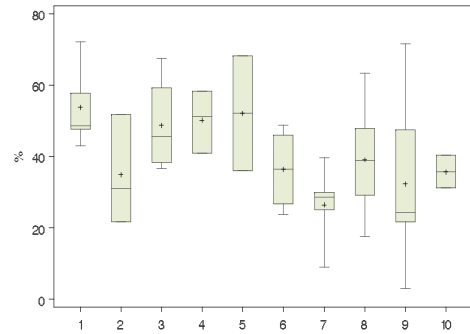
Panel A: Local rates of return by region--Model 1



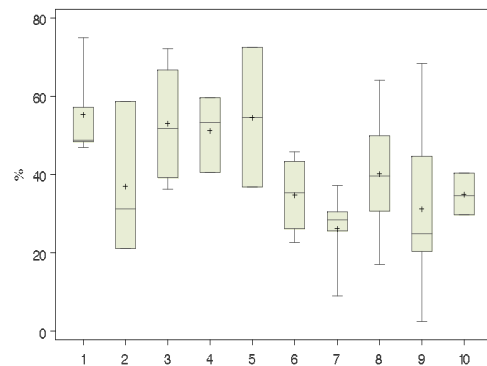
Panel B: Local rates of return by region--Model 2



Panel C: Social rates of return by regions—Model 1



Panel D: Social rates of return by regions—Model 2



Data source: by authors.

Regions 1: Corn Belt; 2: Pacific; 3: North Plains; 4: Lake States; 5: Southern Plains; 6: Southeast; 7: Appalachian; 8: Mountain; 9: Northeast; 10: Delta States

2.5 Summary and Conclusions

This chapter uses state-by-year panel data to estimate the contributions of public research, extension activities, and the transportation network to state agricultural productivity growth rates over the 1980-2004 period. We estimate alternative models, with and without accounting for extension activities and roads, to examine whether these factors influence how local R&D contributes to a state's productivity growth. The statistical significance of the R&D interactive terms with extension activities, road density, and R&D spill-ins, indicate that these "efficiency" variables play an important role in enhancing the utilization and dissemination of local R&D. The negative marginal effects of these efficiency variables show that they amplify the benefits of public research expenditures through the multiplier effect. The distributions of the rates of return show a wider interquartile ranges when the impacts of the efficiency variables are included. This suggests that returns to research are not only conditional on each state's natural resource endowment, but also may be affected by its public infrastructure, its extension activities, and its neighbor's research investment. The estimated average internal rates of return mask regional and state heterogeneity. When the extension and roads variables are included in the analysis we can better explain differences in productivity growth rates among states and regions.

The internal rate of return to public R&D is utilized to evaluate the contribution of research expenditures to productivity growth, as well as derive local and social rates of return. Public R&D's contribution to the reduction in cost declines when other factors (i.e., the efficiency variables) are considered. The estimated local rates of return are around 13%, while the social rates of return are around 45% among regions and models. Use of the model with extension activities and road density allows us to capture the heterogeneity of the estimates among states.

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Appendix 2.1: Internal Rate of Return to Agricultural Research Investment

When ignoring the social effect, the benefit from one dollar of R&D investment to its own state is obtained as the discounted value of all future cost savings. The internal rate of return, r_1 , can be obtained by solving the following equation:

$$1 = -\sum_{\tau=0}^s \frac{\Delta TVC_{t+\tau}}{\Delta R_t} \cdot \frac{1}{(1+r_1)^\tau} = -\sum_{\tau=0}^s \frac{\Delta TVC_{t+\tau}}{\Delta RD_{t+\tau}} \cdot \frac{\Delta RD_{t+\tau}}{\Delta R_t} \cdot \frac{1}{(1+r_1)^\tau} \quad (A2.1)$$

where s is the maximum period for the contribution of the research investment can last in the R&D stock construction, R_t is the own-state research investment at time t and $RD_{t+\tau}$ is the own-state R&D stock at time period $t+\tau$. $\frac{\Delta RD_{t+\tau}}{\Delta R_t}$ is the R&D stock at time period $t+\tau$ generated by

one dollar own state research investment at time t . In this study, $\frac{\Delta RD_{t+\tau}}{\Delta R_t}$ is the weight at each period to construct the R&D stock from the research investment at time period t .

$$\frac{\Delta RD_{t+\tau}}{\Delta R_t} = \omega_\tau \quad (A2.2)$$

The average impact on total variable cost from a one-dollar increase in a state's agricultural research stock can be expressed as:

$$\frac{\Delta TVC}{\Delta RD} = \frac{\Delta \ln TVC}{\Delta \ln RD} \frac{\overline{TVC}}{\overline{RD}} = \varepsilon_{RD} * \frac{\overline{TVC}}{\overline{RD}} \quad (A2.3)$$

The TVC is the predicted TVC based on the model estimates. The internal rate of return at the sample mean can be obtained by substituting equations (3), (A.2), (A.3) into (A.1), and solving for r_1 :

$$1 = -\sum_{\tau=0}^s \left[r_{RD} + r_{RDRD} \overline{\ln RD} + \sum_{i=1}^4 \theta_{iRD} \overline{\ln w_i} + \sum_{l=1}^3 \phi_{lRD} \overline{\ln y_l} + \sum_{h=1}^3 \xi_{hRD} \overline{\ln E_h} \right] * \frac{\overline{TVC}}{\overline{RD}} * \frac{\omega_\tau}{(1+r_1)^\tau} \quad (A2.4)$$

or

$$1 = -\left[r_{RD} + r_{RDRD} \overline{\ln RD} + \sum_{i=1}^4 \theta_{iRD} \overline{\ln w_i} + \sum_{l=1}^3 \phi_{lRD} \overline{\ln y_l} + \sum_{h=1}^3 \xi_{hRD} \overline{\ln E_h} \right] * \frac{\overline{TVC}}{\overline{RD}} * \sum_{\tau=1}^s \frac{\omega_\tau}{(1+r_1)^\tau} \quad (A2.5)$$

Taking into account the benefits through R&D spillover effect to other states, the internal rate of return can be derived by solving for r_2 in the following equation:

$$1 = \sum_{\tau=0}^s \frac{-\Delta TVC_{it+\tau}}{\Delta R_{it}} * \frac{1}{(1+r_2)^\tau} + \sum_{j=1}^{n-1} \sum_{\tau=0}^s \frac{-\Delta TVC_{jt+\tau}}{\Delta R_{it}} * \frac{1}{(1+r_2)^\tau} \quad (A2.6)$$

where n is the number of the states within a region or group. Therefore, the number of states benefiting from state i 's spillover effect is $n-1$. The first part of equation (A.6) is the own-state benefit discussed in equation (A.1). The second part of the equation is the social benefits generated by i state's research and can be expressed as the follows.

$$\sum_{j=1}^{n-1} \sum_{\tau=0}^s \frac{-\Delta TVC_{jt+\tau}}{\Delta R_{it}} * \frac{1}{(1+r_2)^\tau} = \sum_{j=1}^{n-1} \sum_{\tau=0}^s \frac{-\Delta TVC_{jt+\tau}}{\Delta SR_{jt+\tau}} * \frac{\Delta SR_{jt+\tau}}{\Delta R_{it}} * \frac{1}{(1+r_2)^\tau} \quad (A2.7)$$

The spill-ins generated by one dollar of investment in state i for state j at time period t is the same weight which own R&D stock was constructed.

$$\frac{\Delta SR_{jt+\tau}}{\Delta R_{it}} = \omega_\tau \quad (A2.8)$$

The average impact on one state's total variable cost from its research spill-ins can be expressed as:

$$\frac{\Delta TVC}{\Delta SR} = \frac{\Delta \ln TVC}{\Delta \ln SR} \frac{\overline{TVC}}{\overline{SR}} = \varepsilon_{SR} * \frac{\overline{TVC}}{\overline{SR}} \quad (A2.9)$$

The internal rate of return including the social benefits at the sample mean can be obtained by substituting equations (4), (A.5), (A.7)-(A.9) into (A.6), and solving for r_2 :

$$1 = - \left[r_{RD} + r_{RDRD} \overline{\ln RD} + \sum_{i=1}^4 \theta_{iRD} \overline{\ln w_i} + \sum_{l=1}^3 \phi_{lRD} \overline{\ln y_l} + \sum_{h=1}^3 \xi_{hRD} \overline{\ln E_h} \right] * \frac{\overline{TVC}}{\overline{RD}} * \sum_{\tau=1}^s \frac{\omega_\tau}{(1+r_2)^\tau} - \sum_{j=1}^{n-1} \sum_{\tau=0}^s (\xi_{SRRD} \overline{\ln RD_j} + \sum_{i=1}^4 \rho_{iSR} \overline{\ln w_{ij}}) * \frac{\overline{TVC_j}}{\overline{SR_j}} * \frac{\omega_\tau}{(1+r_2)^\tau} \quad (A2.10)$$

While the internal rate of return can be estimated at a specific point, such as at the mean, it can also be measured in each observation.

Appendix Table A2.1 - Parameter Estimates, US agricultural productivity, 1980-2004

Parameters	Model 1		Model 2		Parameters	Model 1		Model 2	
	coefficients	t ratio	coefficients	t ratio		coefficients	t ratio	coefficients	t ratio
β					θ				
β_V	1.1167	4.01 ***	1.472	5.46 ***	θ_{ARD}	-0.0159	-5.86 ***	-0.0165	-6.06 ***
β_C	-1.2364	-4.72 ***	-0.631	-2.59 ***	θ_{MRD}	-0.0008	-0.16	-0.0044	-0.94
β_O	-0.0442	-0.15	-0.505	-1.81 *	θ_{KRD}	-0.0127	-6.55 ***	-0.0129	-6.88 ***
β_{VV}	0.0242	1.03	0.040	1.80 *	θ_{LRD}	0.0294	8.22 ***	0.0338	9.58 ***
β_{VC}	-0.0168	-0.88	-0.014	-0.77	φ				
β_{VO}	-0.0551	-3.13 ***	-0.060	-3.54 ***	φ_{VRD}	-0.0087	-0.55	-0.0416	-2.73 ***
β_{CC}	0.1672	8.3 ***	0.121	6.19 ***	φ_{CRD}	0.0719	5.01 ***	0.0498	3.7 ***
β_{CO}	-0.1465	-8.55 ***	-0.117	-7.16 ***	φ_{ORD}	0.0242	1.49	0.0453	2.95 ***
β_{OO}	0.2073	7.8 ***	0.183	7.28 ***					
γ					ξ				
γ_{RD}	-0.6938	-1.52	-0.487	-1.16	ξ_{ETRD}	--	--	-0.0154	-18.82 ***
γ_{RDRD}	-0.0255	-1.16	-0.010	-0.50	$\xi_{RO RD}$	--	--	-0.0021	-4.38 ***
					$\xi_{SR RD}$	-0.0088	-10.28 ***	-0.0091	-12.45 ***
α					ρ	--	--		
α_{AA}	0.0457	16.73 ***	0.049	17.96 ***	ρ_{ETA}	--	--	-0.0106	-4.11 ***
α_{AM}	-0.0316	-9.62 ***	-0.035	-10.57 ***	ρ_{ROA}	--	--	-0.0063	-3.71 ***
α_{AK}	-0.0029	-1.59	-0.003	-1.61	ρ_{SRA}	-0.0192	-4.21 ***	-0.0159	-3.45 ***
α_{AL}	-0.0112	-5.14 ***	-0.011	-4.87 ***	ρ_{ETM}	--	--	0.0636	13.04 ***
α_{MM}	0.1650	22.32 ***	0.161	21.39 ***	ρ_{ROM}	--	--	0.0096	3.15 ***
α_{MK}	-0.0832	-16.17 ***	-0.076	-14.89 ***	ρ_{SRM}	0.0113	1.54	0.0112	1.52
α_{ML}	-0.0501	-12.33 ***	-0.050	-11.77 ***	ρ_{ETK}	--	--	-0.0210	-11.5 ***
α_{KK}	0.1432	25.98 ***	0.135	24.60 ***	ρ_{ROK}	--	--	-0.0056	-4.72 ***
α_{KL}	-0.0571	-29.29 ***	-0.056	-28.77 ***	ρ_{SRK}	0.0008	0.25	-0.0006	-0.17
α_{LL}	0.1184	33.28 ***	0.117	31.58 ***	ρ_{ETL}	--	--	-0.0320	-9.04 ***
δ					ρ_{ROL}	--	--	0.0023	1.04
δ_{AV}	-0.0282	-14.77 ***	-0.029	-15.17 ***	ρ_{SRL}	0.0070	1.21	0.0051	0.87
δ_{AC}	0.0137	6.05 ***	0.012	5.29 ***	ρ_{WA}	-0.0003	-0.51	-0.0002	-0.39
δ_{AO}	0.0045	1.9 **	0.003	1.35	ρ_{WM}	0.0007	1.11	0.0007	1.05
δ_{MV}	0.0640	16.55 ***	0.071	19.37 ***	ρ_{WK}	-0.0014	-4.3 ***	-0.0014	-4.24 ***
δ_{MC}	-0.0792	-19.12 ***	-0.067	-16.92 ***	ρ_{WL}	0.0009	1.77 *	0.0009	1.55
δ_{MO}	0.0356	7.94 ***	0.039	9.25 ***					
δ_{KV}	-0.0056	-4.02 ***	-0.009	-6.90 ***	Equations	R ²	adjusted R ²	R ²	adjusted R ²
δ_{KC}	0.0250	15.17 ***	0.021	13.49 ***	LnTVC	0.97	0.97	0.98	0.98
δ_{KO}	-0.0272	-15.26 ***	-0.027	-15.99 ***	S_M	0.39	0.38	0.49	0.48
δ_{LV}	-0.0301	-11.14 ***	-0.033	-12.31 ***	S_K	0.7	0.7	0.74	0.74
δ_{LC}	0.0406	13.68 ***	0.034	11.77 ***	S_L	0.62	0.62	0.66	0.66
δ_{LO}	-0.0129	-3.99 ***	-0.015	-4.87 ***					
					Wald X2				486.68 ***
					L.R.				487.01 ***

Note 1: Model 1 does not include extension and roads variables, Model 2 includes both variables in the estimates.

Note 2: V stands for livestock, C for crops, O for other farm related goods and services, A for land, L for labor,

M for materials, K for capital, RD for own agricultural R&D stock, ET for extension, RO for road density, SR for R&D spillins

Note 3: '***' indicates significant at 1% level. '**' indicates significant at 5% level. '*' indicates significant at 10% level.